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TOW Weapon System Boundaries and Training Evaluation Procedures for the Firing Simulator TOW (SST)

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Onder opdrachtnummer A96KL493 heeft het TNO Prins Maurits Laboratorium (TNO-PML) voor DMKL Afdeling Info. Systemen de verschillende systeembegrenzingen van het TOW wapensysteem onderzocht, ten behoeve van de invoering van de Schiet Simulator TOW (SST). Zowel de schutter-gerelateerde als de niet-schutter-gerelateerde systeembegrenzingen zijn beschouwd.
Het blijkt dat door ongewenst schuttergedrag, met name te snelle rotatie van het TOW-richtmerk, systeembegrenzingen overschreden kunnen worden, met als gevolg dat het TOW missile verloren gaat. De SST moet dergelijke effecten in rekening brengen.
Na de TOW-oefeningen kan de SST-instructeur een evaluatiesessie oproepen. Aan de hand van de evaluatie zal de instructeur de schutter moeten wijzen op de oorzaken van eventueel falen. Uit de analyse blijkt dat de huidige implementatie van de evaluatiemethode de instructeur niet volledig kan ondersteunen. In het rapport wordt een alternatieve evaluatiemethode voorgesteld die de instructeur informatie verschaft waarmee hij de schutter beter kan opleiden en begeleiden.

Statement of GLP Compliance

Report no.: PML 1996-A91

The reported study was performed at the TNO Prins Maurits Laboratory in accordance with the Quality System of the research group Weapon Effectiveness, which is on the level of the ISO 9001 standard, as stated in the project plan SST.

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Date: November 11, 1996

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Quality Assurance Statement

On	: Project System Boundaries Firing Simulator TOW
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Report no.	: PML 1996-A91
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The execution of this study and the processes involved are inspected in accordance with ISO- 9001 as stated in the project plan SST.

This report has been audited according to the appropriate SST project plan (PlanSST96-08-27.KFC) and is considered to be an accurate presentation of the methods and procedures employed and the findings.

Date: January 6, 1997

G.C. Pronk
(Head Quality Assurance Unit)

Contents

Annexes:

1 Introduction

The working group PVT/SST of the Royal Netherlands Army Materiel Directorate/Info. Systems Division (DMKL/Afdeling Info. Systemen) is responsible for the implementation of the Firing Simulator TOW (SST) and the Platoon Firing Control Trainer (PVT). The SST will replace the current TOW gunner training facilities. It is an aiming simulator which will be used to train the aiming performance of TOW gunners. Siemens Nederland N.V. is the main contractor for the development of the SST, while SIMTECH (Israel) and Kolsmann (USA) are also contributing to its development.

Implementation of the SST is currently in an advanced stage. However, DMKL demands some improvements to the SST evaluation session. The gunner firing performance should be presented by using a limited number of parameters and the results should be presented in a clear manner in order to assist the SST instructor in conducting quick assessment of the gunner's performance. If a miss occurs, the instructor should be able to explain to the gunner the cause of the miss. On the other hand, if the target is hit, the instructor should be able to determine whether the hit is a result of the accurate tracking behaviour of the gunner or a coincidence.

With the DMKL assignment A96KL493, the TNO Prins Maurits Laboratory (TNO-PML) was requested to give advice on possible modifications to the SST in order to improve the firing evaluation session. In addition, DMKL also required information on the various system boundaries of the TOW weapon system, both gunner-related and not-gunner-related.

This report gives an account of the TNO-PML study and its results.

Chapter 2 briefly describes the gunner-related TOW missile failures collected from the Fly-to-Buy data.

Chapter 3 describes the gunner-related TOW system boundaries.

Chapter 4 gives a concise description of the not-gunner-related TOW system boundaries.

Chapter 5 discusses the most significant parameters required for the SST firing evaluation. Both the current implementation and the proposed modifications for an improved SST firing evaluation are considered.

The conclusions in Chapter 6 complete this report.

2 TOW System/subsystem failures

In general, the causes of a missile failure can be classified into four different groups:
1 failure due to the launcher;
2 failure due to the missile;
3 failure due to the TOW weapon system interface;
4 failure caused by the gunner.

In [1], the different failure modes observed from the TOW Fly-To-Buy data are collected. The observed missile failures caused by the gunner are also listed in [1]. These failure modes are given as followed:
G1 Rapid motion of the Line-Of-Sight;
G2 Moving the Line-of-Sight to intersect the ground;
G3 Follow missile instead of target;
G4 Failure to recognise and identify target;
G5 Right sight in WFOV when missile is launched;
G6 Improper collimation and boresighting.

The failure modes G5 and G6 are gunner errors prior to the missile launch. Failure modes G5 and G6 can be reduced by including the necessary handling (such as setting the night sight to NFOV and accurate collimation and boresighting procedures) prior to missile launch in the gunner training programme.
Failure mode G4 occurs due to reduced visual capability of the gunner under specific weather conditions (e.g. operation at night or reduced visual range due to fog, rain or smoke). Failure mode G4 may also arise whenever the gunner attempts to fire TOW missiles on two (or more) targets which are close to each other. After the first target is killed, he fires the second missile but hits the previously killed target instead of the second target.
Obviously, in order to improve the gunner aiming behaviour during missile flight, the failure modes G1, G2, G3 should be avoided. Since the Shoot Simulator TOW (SST) is intended to train the gunner's aiming behaviour, the failure modes G1 to G3 should receive sufficient attention. Adequate information should be provided by SST to help indicate the cause of failure after a training session.

3 Gunner-related system boundaries

The previous chapter listed the different causes of TOW missile failures introduced by the gunner. In general, these gunner errors will give rise to situations in which different TOW system boundaries will be surpassed. In the following, the most significant TOW system boundaries will be considered.

3.1 Maximum lateral and vertical acceleration

There are many situations in which the gunner may attempt to introduce a rapid motion of the LOS. Some examples are:
- the gunner attempts to track a fast moving target;
- missile signature is attenuated by smoke, e.g. due to missile launch or caused by artillery shells. After the smoke clears up, the gunner discovers that the tracker reticle is off target, and he introduces rapid movement attempting to bring the reticle back onto the target;
- sudden movement of the gunner; for example, the gunner's shock reaction caused by missile launch.

Maximum acceleration due to fin deflections
The control surfaces (fins) of the TOW missile are driven by a two-position actuator system. For the pitch channel, the extreme positions of the fins are set to -6° and +2°. The asymmetry produces an offset of 2° in order to compensate for gravity bias. The yaw control surface deflections are set at ±6° to provide adequate manoeuvre capability against moving targets. Steering commands shift the duty cycle of the pitch and yaw control surfaces at a rate of 25 (for $t< 4.3$ s) or 12.5 Hz (for $t > 4.3$ s) and determine how long the control surface remains at each extreme position. An estimation of the maximum pitch and yaw accelerations that the missile can achieve with the maximum fin deflections can be found in [2] and [3]. The maximum pitch and yaw accelerations for the ITOW, TOW 2, TOW 2A and TOW2B due to the above-mentioned mechanical limit are given in Figures A.1 to A.8 of Annex A.

Maximum acceleration bounded by the Command Signal Generator
Besides the mechanical limits, Figures A.1 to A.8 also show the electronic limits on the missile accelerations. These limits are laid down by the Command Signal Generator (CSG).
The TOW Digital Missile Guidance Set (DMGS) obtains the instantaneous pitch and yaw Line-Of-Sight (LOS) rates from the tachometer built into the traversing unit.
The tachometer outputs are filtered, amplified and summed with the filtered missile error signal in their respective channels in order to generate the so-called VS3 steering command. In the pitch channel, the gravity bias function is added to

account for gravity. In the yaw channel, the open loop steering is added to steer the missile onto the LOS directly after launch. On generating VS3, the Command Signal Generator limits are applied. This limit function is twofold. First, the commanded missile angle of attack must not exceed the structural capabilities of the airframe. Secondly, the command signal VS3 must be below the levels at which excessive coupling between the steering loops and the roll channel could occur. By applying the VS3 limits, the maximum pitch and yaw accelerations of the missile as given in Figures A.1 to A.8 can be derived. It can be noticed that the electronic limits (due to the VS3 limits) are more critical than the mechanical limits due to the fin deflections.

3.2 Tracker Field of View (FOV) limits

The TOW missile is tracked by the OSS (Optics Sensor/System) day sight tracker or the VTT (Video Thermal Tracker) night sight tracker.
For all TOW missile types except the TOW 2B, the window limits of the OSS tracker are:

- Wide Field of View (WFOV) = 4° (69.6 mrad) for $t < 1.76$ s;
- Narrow Field of View (NFOV) = 0.5° (8.7 mrad) for $t > 1.76$ s.

(For TOW 2B, the tracker switches from WFOV to NFOV at $t = 2.0$ s.)

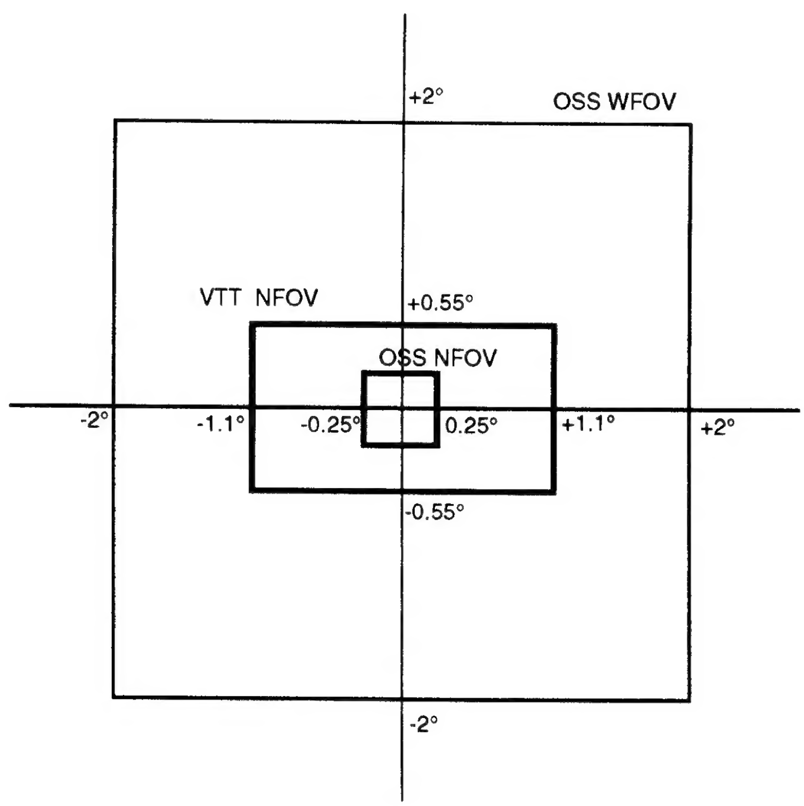

Figure 3.1: TOW OSS and VTT trackers Fields of View.

For the night sight tracker, the NFOV must be switched on prior to missile launch. Therefore, the NFOV angle becomes the window limit of the night sight tracker for the entire missile flight.
TOW VTT NFOV angle is:

- vertical : $1.1 \pm 0.1°$;
- horizontal : $2.2 \pm 0.2°$ ($\approx$ 19 mrad left and 19 mrad right).

The various view windows are depicted in Figure 3.1.
(Note: the WFOV may be used to locate a target. However, if the switch is left in the WFOV, the guidance signals from the VTT will not be able to guide the missile.)

3.3 Maximum missile body-to-LOS angle

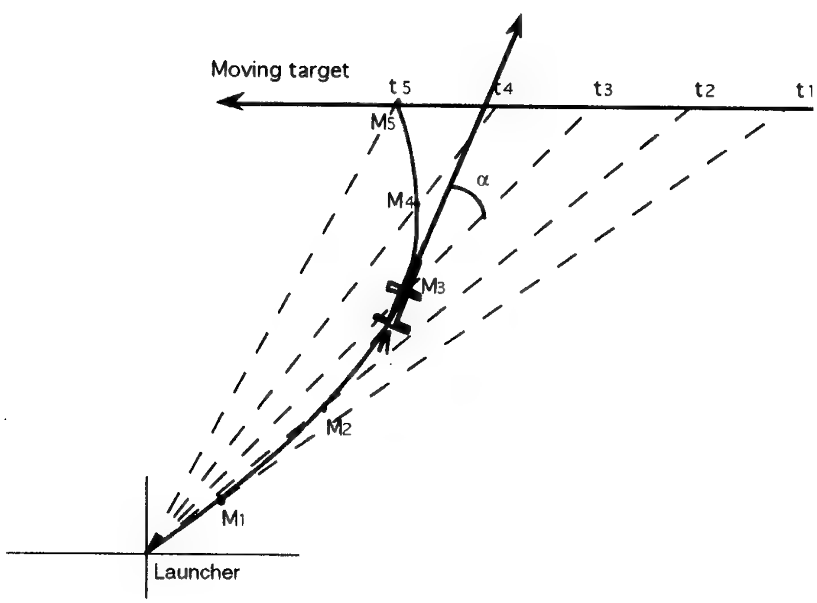

Figure 3.2: TOW missile Body-to-LOS angle.

The TOW missile carries a xenon beacon and a thermal beacon to transmit position information to the day sight tracker and the night sight tracker, respectively. The beacons will have a limited beam-width and, if the gunner introduces rapid LOS motion such that the missile Body-to-LOS angle exceeds this limit, a serious loss of signal will result. In [4], a 40° limit (or ±20°) is quoted as the general limit for beacons. As illustrated by Figure 3.2, the TOW missile has to pull a turn in order to follow a moving target. In general, the missile body-to-LOS angle α increases as the rotational rate of the LOS is increased. This relation holds until the maximum lateral or pitch acceleration of the missile is reached.

If the rotational rate of the LOS is too high, the missile may begin to slip away from the LOS or the body-to-LOS angle may become too large, so that the tracker signals will be lost, whichever happens first.

3.4 Elevation boundary due to terrain

As stated earlier, one of the major causes of a missile loss is introduced by the gunner when he moves the LOS to intersect the ground. This gunner error can be trained and reduced, depending on how realistic the terrain information is incorporated into the SST.

3.5 Target recognition

Missile failure due to target recognition is partially gunner-related. In the situation where the gunner is confronted with two or more targets closed to each other, his capability to identity and hit the different targets can be trained with the SST. Target recognition capability of the gunner can also be degraded by environmental disturbances such as jammers and atmospheric attenuation. The gunner's capability to identify and trace the target under such conditions can be trained with or without the SST.

3.6 Concluding remarks

In Chapters 3.1 to 3.5, the different 'gunner-related' system boundaries have been considered.

The first three system boundaries are related to the rotational rate of the tracker reticle introduced by the gunner. When the gunner moves the tracker reticle quickly, one of these system boundaries may be surpassed and the missile will be lost.
Amongst the three system boundaries, the maximum lateral and vertical acceleration of the missile is considered to be most critical. Very often, the maximum lateral or vertical acceleration will be exceeded first before the other system boundaries are surpassed. However, there are also certain circumstances under which the tracker FOV limits are more critical, for example, directly after tube-exit when the launch transients are not yet completely damped out. This is also the reason why the day sight tracker remains in the WFOV until $t > 1.76$ s.
Under normal operational conditions, the missile body-to-LOS angle is believed to be less critical. There may be specific situations in which this system boundary will become more critical than the other system boundaries. These situations have to be determined numerically from detailed simulations and are beyond the scope of this study.

The elevation boundary due to the terrain and the gunner's capability for target recognition are not directly related to the *rotational rate* of the tracker reticle. Instead, these features are indications of how the gunner reacts to the environment information which he observes through the tracker optics. It is essential to have these features implemented in detail in order to improve the effectiveness of the SST training. Since the SST simulator was not available for demonstration to TNO-PML during this writing, no further consideration will be given to these features.

4 Other system boundaries

In practice, a TOW missile flight involves many noise sources which lead to the non-ideal behaviour of one of the system components or to other non-controllable phenomena. Examples of the most important noise sources are:

1 wind;
2 boresight error bias in day sight and night sight system;
3 fin deflection upper and lower bounds vector;
4 incremental moment factor due to thrust misalignment (in pitch, yaw and roll);
5 angular bias of launch tube with respect to tracker LOS;
6 missile body rotation due to tip off (in pitch, yaw and roll);
7 missile mass and inertia due to motor and wire;
8 total launch motor impulse;
9 air temperature.

The most influential noise source appears to be the wind velocity, followed by the pitch tip-off rate and the yaw tip-off rate. Influence of these two noise sources on the TOW weapon system will be discussed in this chapter. Furthermore, system limitations due to the traversing unit, jammers, atmospheric attenuation, smoke and countermeasures will be considered.

4.1 Missile tip-off rate

The missile tip-off rate arises due to missile chatter in the tube, motor thrust axis misalignment, and force of gravity (pitch only). Normally, a TOW missile can withstand a relatively high tip off rate. However, when a high tip off rate occurs in conjunction with a strong crosswind or tailwind, the missile may become unstable shortly after launch and may become uncontrollable.

4.2 Wind effect

Wind effect on the TOW 2A flight characteristics was investigated in a recent study conducted at TNO-PML by using the US Army MICOM TOW simulation [6]. Some of the general characteristics of the MICOM TOW simulation are given in Annex B. Results of the study can be summarised as follows.

Crosswind: the TOW 2A missile can withstand crosswinds up to quite a high velocity (about 20 m/s). In general, a crosswind blowing from left to right of the LOS is more critical. The reason is that directly after launch, the TOW missile will be located on the right-hand side of the LOS. The yaw open loop steering is used to steer the missile onto the LOS. With a strong crosswind blowing from right to left after tube exit, a shoot over behaviour will lead to missile loss.

Head-/tailwind: directly after tube-exit, the TOW missile is accelerated by the flight motor. With a strong tailwind, the relative velocity of the missile with respect to the air will decrease and the wings may not be able to generate enough lift.
By contrast, headwind will increase the relative velocity of the missile with respect to the air and therefore enhance its stability shortly after launch. Headwind increases the missile's time of flight to target but has no negative effect on its stability.

4.3 Jammers

The day sight tracker sensor responds to the short-wavelength (SWL) infrared radiation of the xenon source in the missile, while the night sight tracker responds to the long-wavelength (LWL) infrared of the thermal beacons.
Normally, the TOW missile is guided by the OSS day sight tracker. In circumstances where the day sight tracker may lose the missile (e.g. due to day sight jammer or smoke), the guidance system switches from OSS day sight to VTT night sight tracking. This is the so-called Hand-off. In general, the gunner will not notice whether the missile guidance software is using the OSS or VTT tracker.
The effect of jammers on the missile flight characteristics demands extensive study due to the wide variety of jammers that can be applied. The probability that the trackers will lose the missile depends on the shape, the size and the intensity of the jammers. It also depends on the number of jammers and their positions within the FOV. In some studies conducted at TNO-PML, the effect of jammers on the TOW weapon system was investigated in details. These studies have been reported in [7] and [8].

4.4 Atmospheric attenuation

The effect of atmospheric attenuation on the TOW trackers due to fog was investigated through a recent study conducted at TNO-PML. Fog with different intensities was considered, which correspond to different visual ranges. Results concerning the performance of the day sight tracker and night sight tracker due to fog attenuation and the effect on the TOW missile flight characteristics are given in [6].

4.5 Smoke and countermeasures

One of the system limitations of the TOW trackers is that they can be jammed by smoke caused by the missile launch or field-applied countermeasures. Unlike fog or rain, countermeasures and smoke are not widely dispersed over the entire terrain. Furthermore, they are strongly dependent on wind, temperature and turbu-

lence. Under certain circumstances, smoke will only attenuate the sensors for a portion of the flight, and the tracker will then be able to guide the missile to the target.
In general, the day sight tracker can be easily blinded by smoke. On the other hand, the night sight tracker is less sensitive to smoke attenuation and may be able to see through the smoke depending on the intensity and composition of the smoke. In [9], obscurant extinction coefficients of some commonly used countermeasures (e.g. white phosphorus screening smoke, fog oil screening smoke, etc.) are given. With these data, the influence of countermeasures on the TOW tracking system could be analysed in the future.

4.6 Traversing unit elevation limits

The TOW missile trackers are mounted on the traversing unit of the TOW launcher. The traversing unit provides for rotation of the sights and launch tube between 30° up and 20° down in elevation, and 360° in azimuth. Since the TOW launcher is coupled to the SST, the elevation limits due to the traversing unit are identical to the field situation and no further consideration is required.

4.7 Concluding remarks

In Chapters 4.1 to 4.6, different 'not-gunner-related' system boundaries have been considered. These system boundaries arise due to environmental factors (e.g. wind, fog, rain, snow, etc.) or field-applied countermeasures (e.g. jammers and smokes). Effects of wind and fog have been investigated through some recent studies at TNO-PML. Influences of rain and snow were not investigated but can be studied in the future. Effect of some specific jammers on the performance of the TOW trackers have been determined through some recent TOW studies at TNO-PML. However, there are continuous developments in the area of jammers and countermeasures (like screening smokes). In the future, effects of the newly developed countermeasures should be investigated through extensive simulations.

5 Instructor evaluation of the TOW firing session

5.1 Useful parameters for the training evaluation

During a training session, the Firing Simulator TOW (SST) generates different targets on a given terrain. The targets may be stationary or moving with a specific velocity or acceleration. The gunner will have to select a target and then fire the missile. Throughout the entire missile flight, the gunner has to guide the missile by keeping the tracker reticle on the target. The missile guidance software measures the angular position of the missile with respect to the tracker reticle and determines the steering command which is necessary to keep the missile following the reticle as well as possible.

With reference to Figure 5.1, the target position in a horizontal plane can be defined by the angle α_y. The direction of the tracker reticle is given by β_y, while the missile position is given by the angle γ_y. For the SST, the target position α_y is an input to a training session which is prepared and saved in a database within the simulator. As the gunner is tracking a target, the rotational rate of the launcher is registered by the tachometer. The angular position β_y of the tracker reticle can be determined from the tachometer output. The angle $(\beta_y - \alpha_y)$ is a parameter which shows how well the gunner is tracking the target during the missile flight.

Based on the tracker reticle movement introduced by the gunner, the TOW flight path model within the SST computes the missile position γ_y. According to Siemens, this flight path model is delivered by Perceptronix (USA), and detailed specifications of the model are not available. For the SST, this flight path model replaces the Digital Missile Guidance Set (DMGS) hardware of the TOW weapon system. The angle $(\gamma_y - \beta_y)$ is a parameter indicating how accurate the missile is guided by the missile guidance software.

After the training session, useful data should be presented in a simple and compact manner so that the instructor can conduct a quick assessment of the gunner's aiming behaviour. The instructor must be able to determine whether the gunner has performed a correct TOW firing. If a miss occurs, the instructor must be able to explain the cause of failure based on the evaluation. Time required for the assessment must be very short and gunner performance should be illustrated with a limited number of parameters.

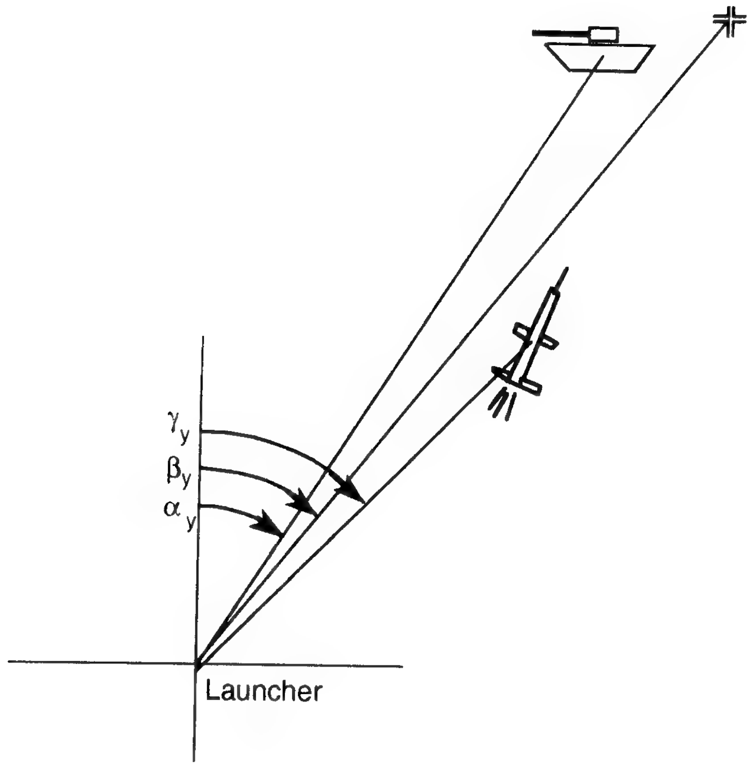

Figure 5.1: Angular position of the target, tracker reticle and missile.

5.2 Suggested evaluation methods and associated problems

For the evaluation after a training session, Siemens suggested that the angle (β - α) between the target and the tracker reticle can be plotted against the missile flight time in a graphical window. Two data plots, one for the pitch plane and the other for the yaw plane, will be presented in the same graphical window. Furthermore, it is also suggested that a certain limit on the angle (β - α) can be plotted on the same graph to indicate when the gunner aimpoint error angle exceeds the maximum allowable value. There are certain problems associated with this approach. These problems will be discussed in the following paragraph.

First of all, the envelope on the angle (β - α) is a function of the missile velocity and the tracker reticle movement during the missile flight. At the beginning of the flight when the missile velocity is increased by the flight motor, the missile will be able to pull large pitch and yaw accelerations. After the flight motor burns out, the pitch and yaw accelerations that the missile can sustain will decrease. The maximum pitch and yaw accelerations of the TOW are given in Figures A.1 to A.8. The envelope on the aimpoint error angle (β - α) is related to the maximum pitch and

yaw accelerations. Figure 5.2 gives an example showing what such an envelope would look like. Note that the envelope of the aimpoint error angle is smaller than the OSS NFOV and will converge as the missile velocity decreases. Furthermore, the envelope for the pitch and yaw channels will be different, since the pitch channel involves gravity compensation while the yaw channel does not.

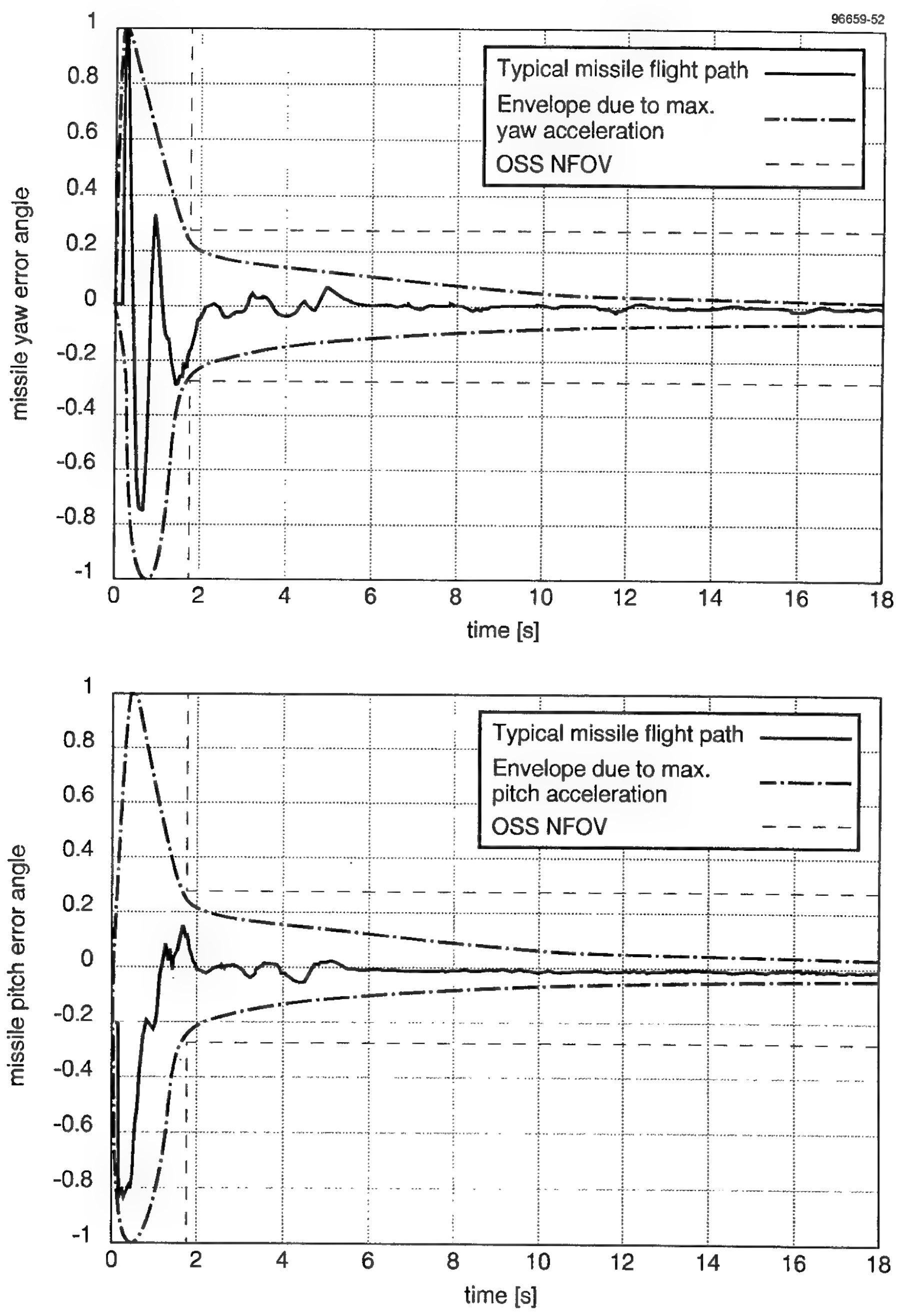

Figure 5.2: TOW pitch and yaw error angle and the related envelopes.

One must also notice that the aimpoint error angle envelope will be different when different target motions are concerned. For example, when tracking a fast moving target, the boundaries on the error angle (β - α) will be smaller than in situations where the missile is fired against a slow or stationary target. In other words, for each target motion implemented in the SST, a different envelope on the aiming error angle will have to be computed and stored. Due to the large number of target motions involved in the SST, this will require extensive simulation effort. Therefore, it will not be feasible to use the envelopes of the aimpoint error angle for the SST evaluation.

Another problem associated with the suggested approach is that the aiming error angle (β - α) only shows how well the gunner is tracking the target. It will not help the instructor to explain why a missile misses a target.

The above-mentioned problems were discussed during a meeting between Siemens and TNO-PML. It was concluded that the SST evaluation module has to be extended and additional graphical outputs should be provided to support the SST evaluation.
Afterwards, Siemens suggested that an additional graph showing the missile error angle (γ - β) in pitch and yaw will be plotted against missile flight time and the envelope of the missile error angle will be shown on this additional graph (see Reference [10]).

However, for the same reasons as mentioned previously, it is not feasible to include the envelope of the missile error angle for the SST evaluation. Furthermore, the missile error angle (γ - β) and the aimpoint error angle (β - α) together will not be sufficient to support the SST instructor in conducting an evaluation for all scenarios.

5.3 Recommended modifications to the evaluation method

In order to provide adequate support to the SST instructor, the following three parameters should be plotted in two separate graphs showing the pitch and yaw channel, respectively:

- α: angular position of the target;
- β: angular position of the tracker reticle;
- γ: angular position of the missile.

In the following, several examples will be given to show why all three parameters are equally necessary for the firing evaluation.
For all examples given below, the angular positions β of the reticle have been generated using a simplified model, since no SST training data is available. In all cases, only the yaw channel will be considered. Similar results can also be derived for the pitch channel provided that the influence of gravity is included.

For examples 1 to 4, different target motions have been chosen, while the aimpoint error angle (β - α) has been kept the same. In the following discussion, it will be shown that the missile flight behaviour will be different for the different target motions considered and the STT instructor will need additional information to conduct a quick assessment of the training session.
In example 5, a sudden movement of the gunner is inserted to show how the missile will react and what the SST instructor will see during the evaluation session.

Example 1: Stationary target
In the case of a stationary target, the angular position α of the target remains zero for the entire missile flight. With the gunner movement described by β, the missile flight path was computed using the MICOM TOW simulation and the resulting missile angular positions are plotted in Figure 5.3.

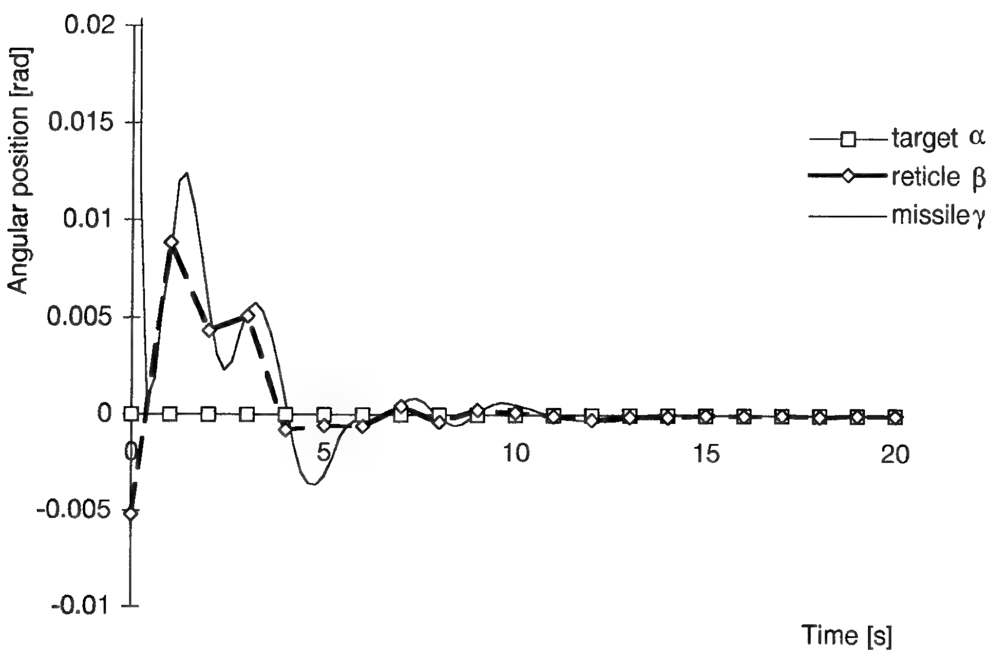

Figure 5.3: Angular position of the target, tracker reticle and missile (example 1).

During an evaluation session, the SST instructor will notice from this graph that the gunner aiming error β is relatively large in the beginning of the missile flight. This also results in a large missile error angle γ. After t = 4 s, the gunner corrects the aiming error and the reticle gets closer to the target position. The missile follows the tracker reticle and the missile error angle converges to zero towards the end of the flight.

Example 2: Target moves with constant velocity 18.7 m/s
(LOS rotational rate = 5 mrad/s)

For this example, the gunner aiming behaviour is identical to that of example 1, since the same angular positions β of the reticle are used.

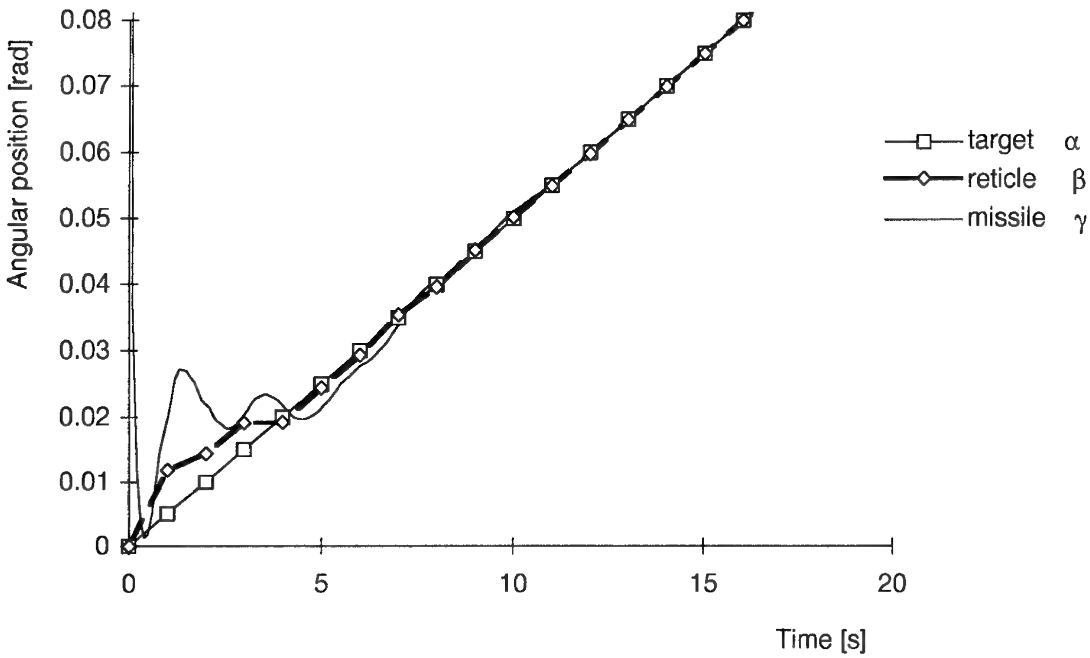

Figure 5.4: Angular position of the target, tracker reticle and missile (example 2).

In an evaluation session, the instructor will see the graphs as shown in Figure 5.4. From these graphs, the instructor will notice that the gunner is tracking a slow moving target. The slope of the graph is an indication of the target velocity. A gentle slope means that the target is moving slowly. In this example, the gunner aiming error is normal and the missile has no problem following the tracker reticle.

Example 3: t <= 16 s: target remains stationary; t >16 s: target moves with constant velocity 18.7 m/s (LOS rotational rate = 5 mrad/s)

For this example, the gunner aiming behaviour is the same as for examples 1 and 2. At t = 16 s, the target begins to move at the same velocity as example 2. The resulting missile flight path is computed by means of the MICOM TOW simulation and is given in Figure 5.5. It can be observed that although the gunner is tracking the target accurately, the missile cannot follow the tracker LOS and will miss the target.

Supposing that the aimpoint error angle (β - α) and the missile error angle (γ - β) are used for the evaluation session (as proposed by Siemens), the instructor will notice that the gunner is tracking the target accurately towards the end of flight, while at 16 s the missile suddenly diverges from the tracker LOS. The fact that the

target begins to move at a certain velocity at 16 s and gives rise to a miss cannot be derived from such data.

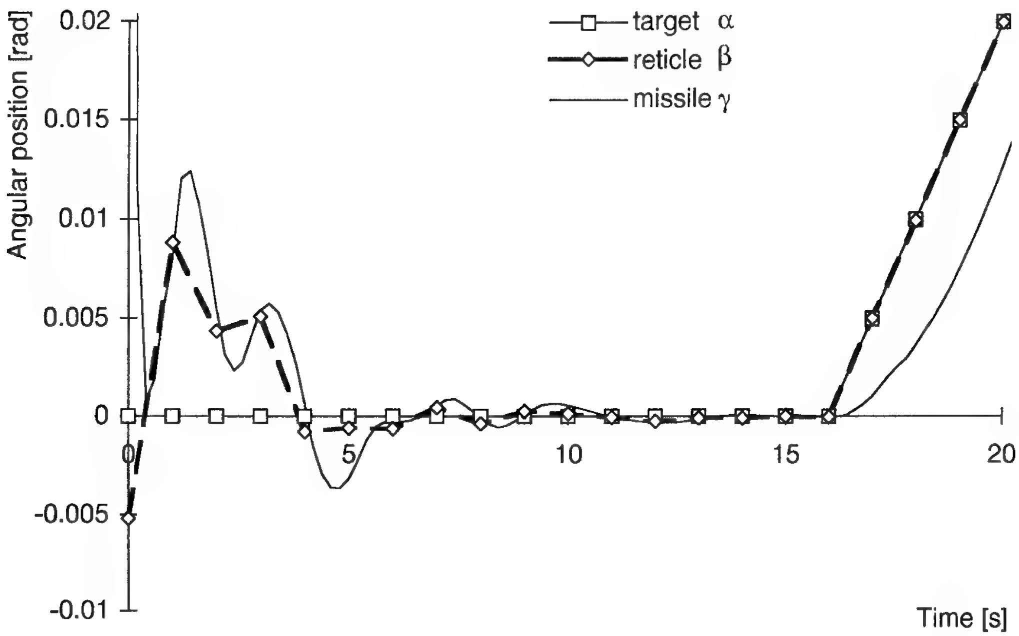

Figure 5.5: Angular position of the target, tracker reticle and missile (example 3).

Example 4: Target moves with constant velocity 93.5 m/s (LOS rotational rate = 25 mrad/s)

In this example, a fasting moving target (e.g. a helicopter) is used. The aimpoint error angle (β - α) in this example is kept the same as examples 1 to 3. With the angular position of the target, reticle and missile plotted against time as shown in Figure 5.6, the instructor will find that the missile begins to lose track of the target from t > 6s. The reason for this can be found in the target motion. From the slope of the graph, the instructor will notice that the target is moving at a velocity (250 mrad in 10 seconds). The gunner moves the tracker reticle with almost the same rotational rate as the target, but the missile is limited by the maximum lateral acceleration and fails to follow the tracker reticle. Towards the end of the flight, the maximum lateral acceleration of the missile decreases due to the decreasing missile velocity. As a result, the missile error angle (γ - β) diverges towards the end of the flight.

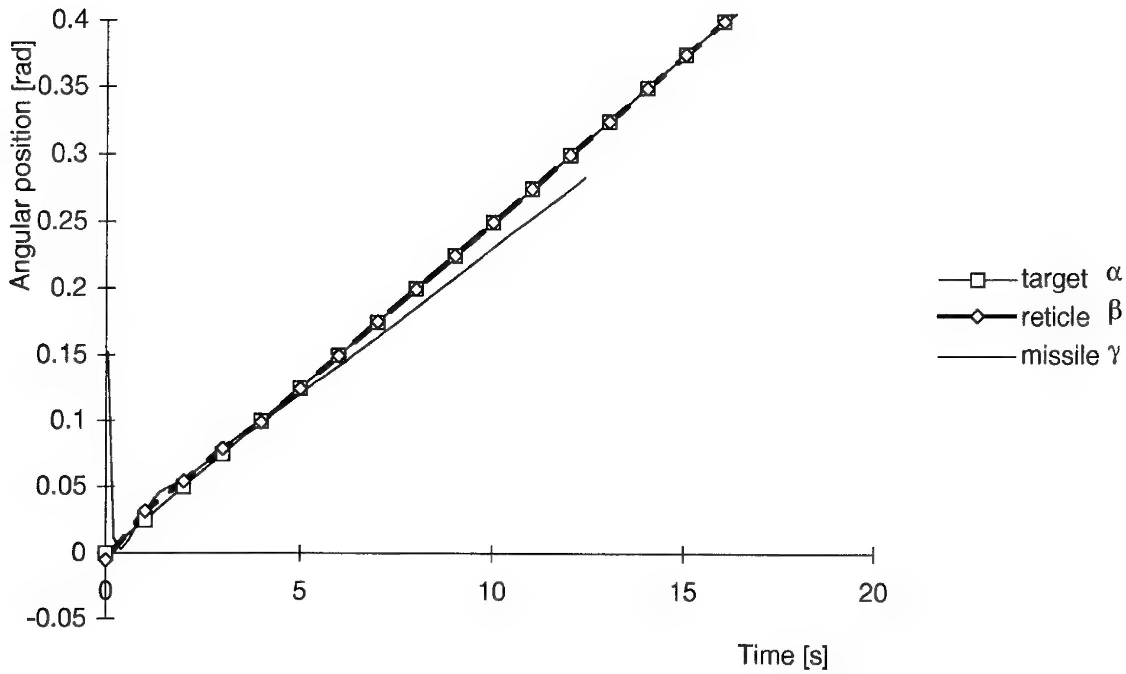

Figure 5.6: Angular position of the target, tracker reticle and missile (example 4).

Example 5: Gunner sudden movement at 15 s

In this example, a sudden movement of the gunner is inserted. Figure 5.7 shows the angular positions of the target, tracker reticle and missile as a function of missile time of flight. From this figure, the instructor will conclude that the gunner is firing the TOW at a stationary target. He will also notice that the sudden movement of the gunner at 15 s causes the missile to lose track of the target. The gunner restores the tracker reticle back onto the target at 18 s. However, the missile cannot follow the tracker reticle due to the low velocity at that moment and is lost.

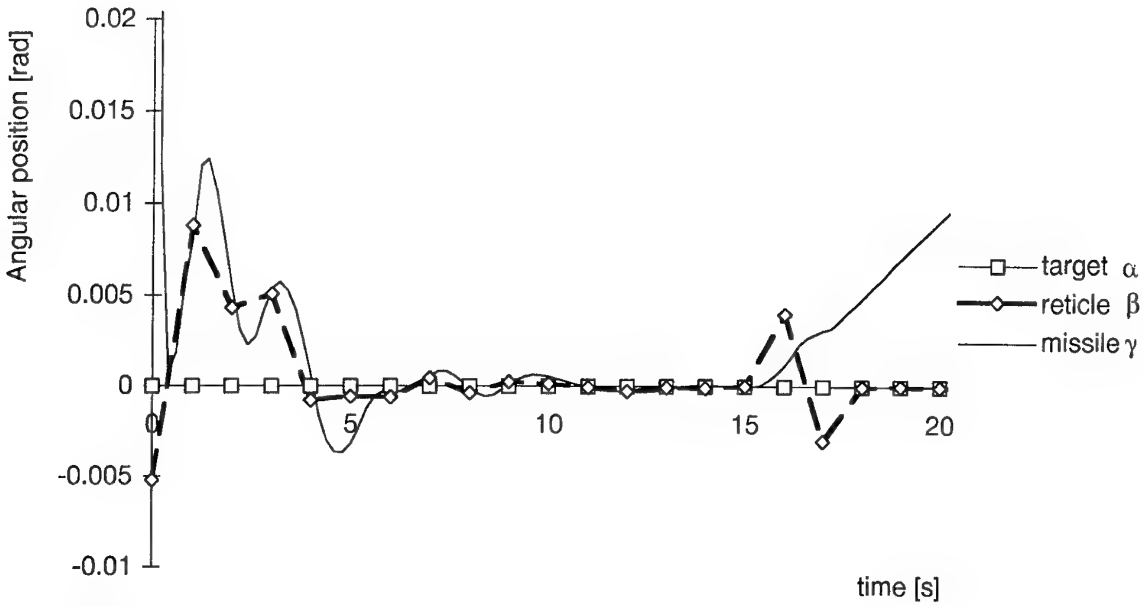

Figure 5.7: Angular position of the target, tracker reticle and missile (example 5).

5.4 Other modifications required to support the SST evaluation

From the examples given in Section 5.3, it can be concluded that the angular positions of the target, the tracker reticle and the missile are the three primary parameters required to quickly assess the gunner aiming behaviour and the resulting TOW missile performance.
The SST instructor will have to conduct the assessment individually for the pitch and the yaw channels. This is due to the different flight characteristics of the missile and the difference in the pitch and yaw control loops of the TOW missile guidance software. The SST instructor should be able to switch between the two channels by pressing a button. The switching between the two channels should be repeatable so that the instructor can view each set of graphs more than once.

Furthermore, the instructor must be able to change the scale of the axes so that he can view the data with more or less detail.
The system should record the gunner movement up to the maximum range of the TOW missile (or the maximum time of flight of about 25 seconds). This will record the complete movement of the gunner, even if he drops the launcher after he sees that the missile loses the target. The flight path model should only be terminated when the missile hits the ground or when the maximum range is exceeded. This will avoid missing data which may be useful for the SST evaluation session.

6 Conclusions

Through the study described in this report, various TOW weapon system boundaries have been investigated. Both the gunner-related and not-gunner-related system boundaries have been considered.
Too rapid movement of the tracker reticle is found to be the most important cause of a miss, as some system boundaries may be surpassed and the missile may then be lost. The lateral and vertical acceleration limits of the TOW missile are considered to be the most critical system boundaries. This is especially significant when the missile is flying down range to the target after the flight motor has burned out. Other gunner-related system boundaries are the tracker FOV limits, the maximum missile body-to-LOS angle, the elevation boundary due to the terrain, and the target recognition capability of the gunner.
After a training session with the SST, the instructor has to evaluate the gunner's performance and explain what went wrong and why a miss occurred. In order to do this, he needs relevant information telling him what actually happened during the firing. The current implementation of the SST evaluation session has several problems associated with it. An alternative form of evaluation is proposed which would provide the SST instructor with more useful information and support him in performing a quick assessment.

In the current study on the SST, only the TOW system boundaries and the improvement to the firing evaluation have been considered. However, in the future, when the SST is in operation, other questions and areas of interest may arise which require more detailed investigation. Some ideas for future work in this field are listed below:

- TOW course for SST instructors, e.g. on technical details of the TOW weapon systems, the functioning of the day sight and night sight trackers;
- verification of the SST flight path model by comparing the simulated SST missile flight paths to those generated by the MICOM TOW simulation. In order to do this, data concerning the movement of the target, the tracker reticle, and the SST missile flight path should be registered and saved in a file;
- calculation of tracker reticle movement envelopes for selected scenarios can serve as additional information to the SST instructor for acquiring better understanding of the TOW weapon system;
- support implementation of other simulators like the PVT or other missile types.

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8 Abbreviations

c.g.	Centre of Gravity
DMKL	Royal Netherlands Army Materiel Directorate
FOV	Field of View
HO	Hand-off
Hand-off	An event in which the guidance system switches from OSS day sight tracking to VTT night sight tracking in situations where OSS may lose the missile.
IR	InfraRed
LOS	Line-Of-Sight
NFOV	Narrow Field of View
OSS	Optical Sight / Sensor
SST	Shoot Simulator TOW (Schiet Simulator TOW)
TNO-PML	TNO Prins Maurits Laboratory
TOW	Tube-launched, Optically-tracked, Wire-guided (missile)
VS0	Angular error (or missile position) with respect to the LOS
VS3	TOW missile steering command
VTT	Video Thermal Tracker
WFOV	Wide Field of View

9 Authentication

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Annex A Maximum missile pitch and yaw accelerations of the TOW missiles

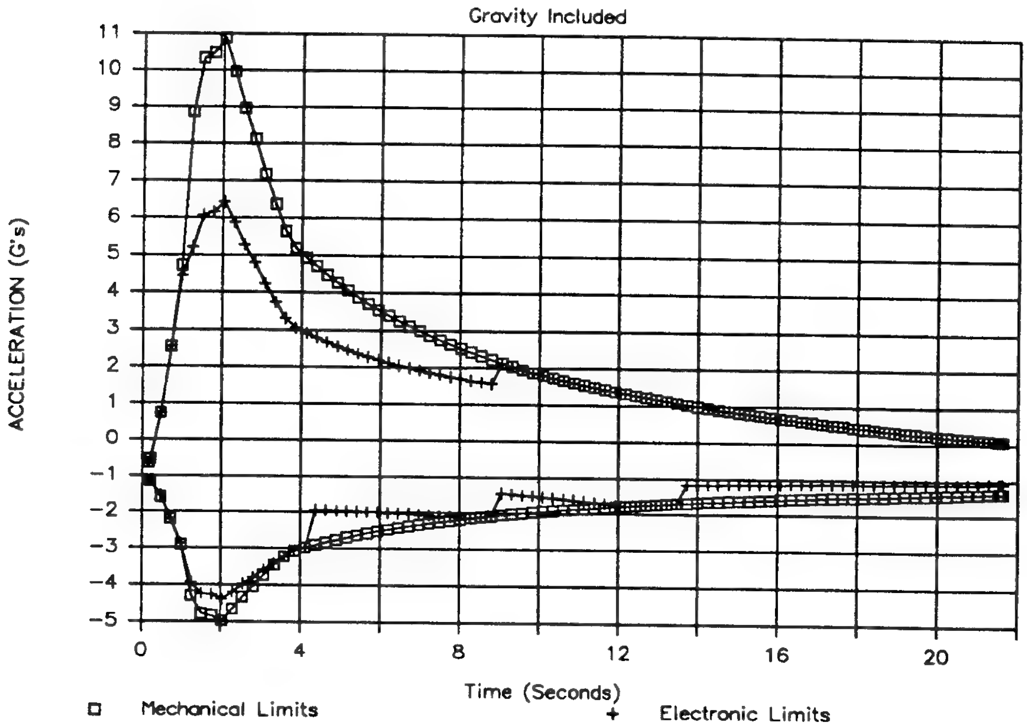

Figure A.1: ITOW Maximum Pitch Acceleration versus Time Profile.

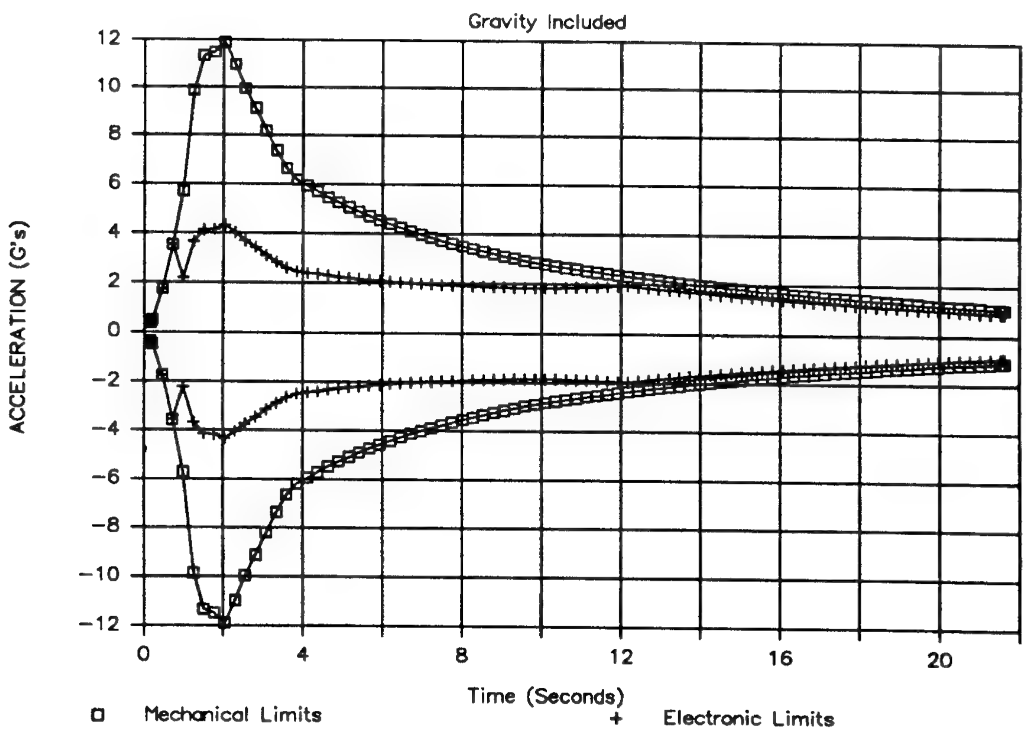

Figure A.2: ITOW Maximum Yaw Acceleration versus Time Profile.

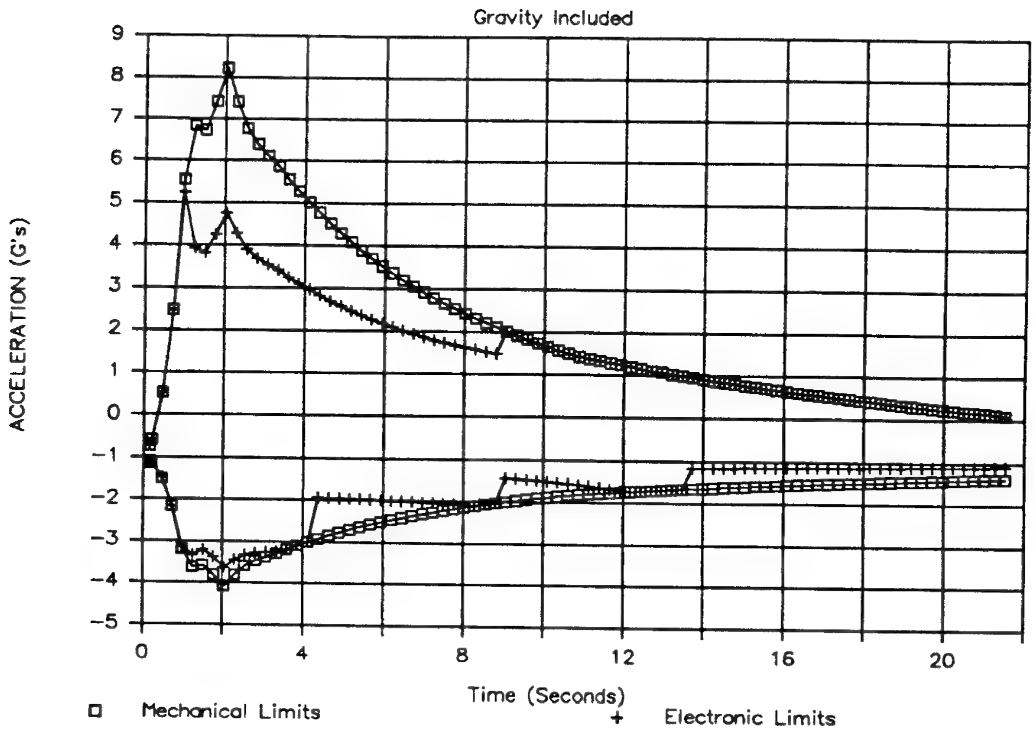

Figure A.3: TOW 2 Maximum Pitch Acceleration versus Time Profile.

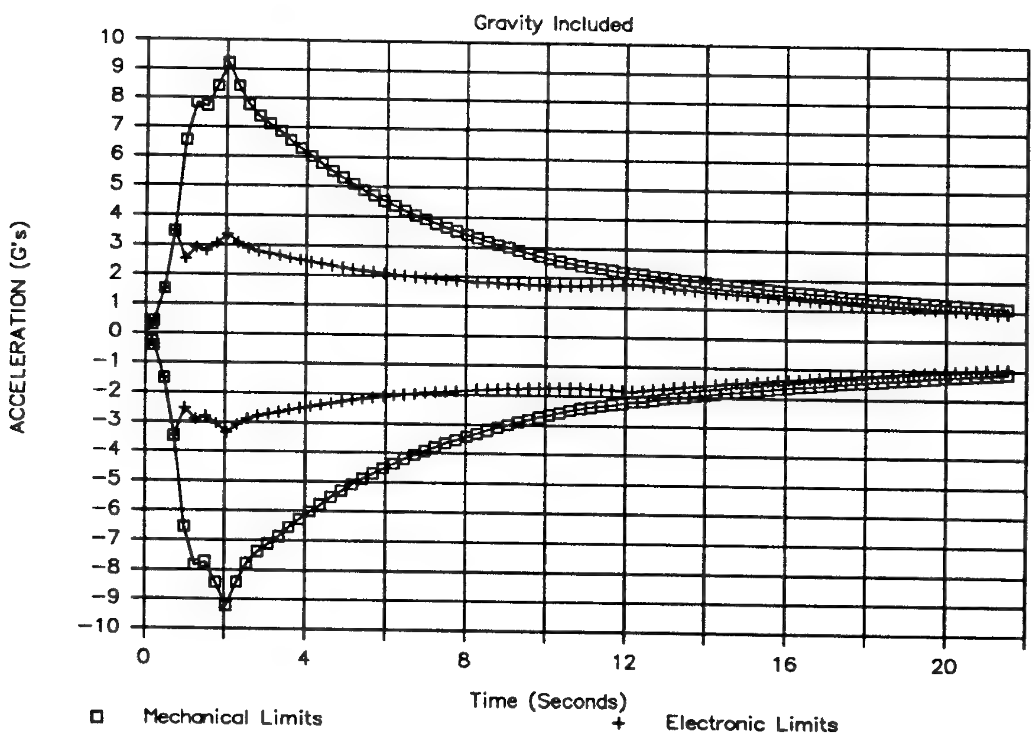

Figure A.4: TOW 2 Maximum Yaw Acceleration versus Time Profile.

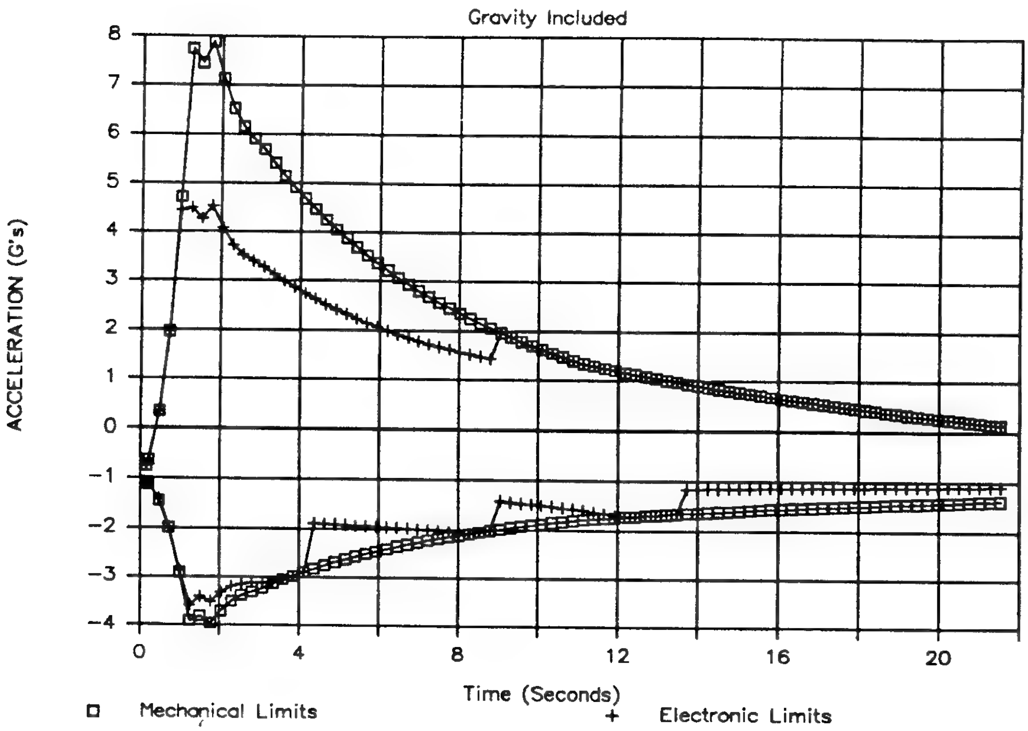

Figure A.5: TOW A2 Maximum Pitch Acceleration versus Time Profile.

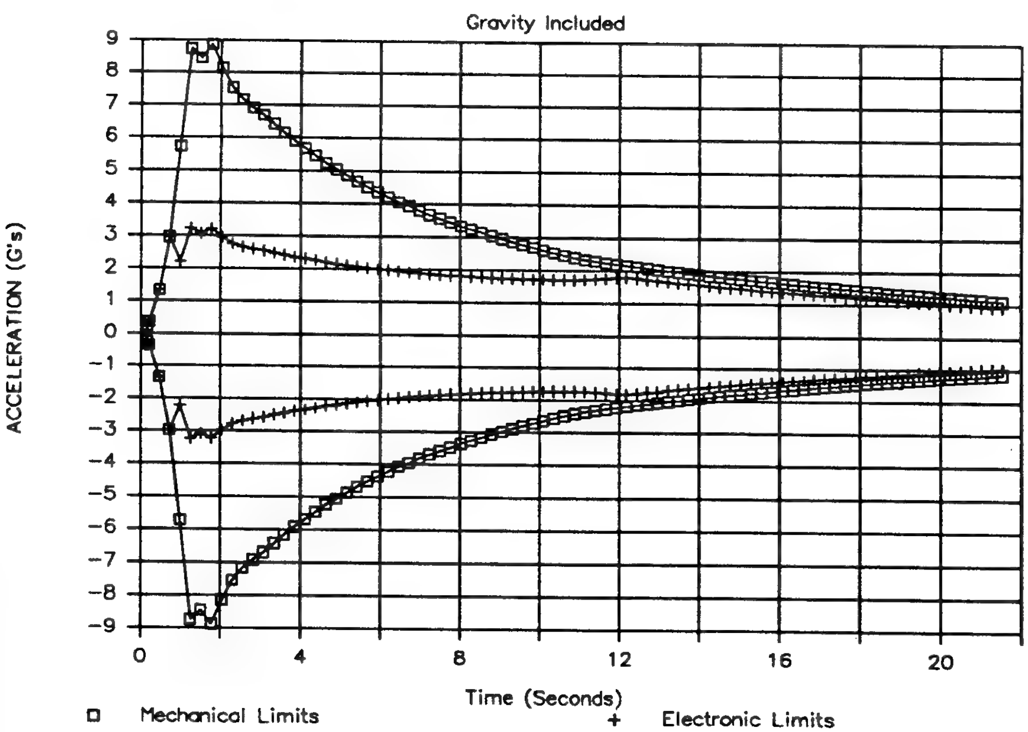

Figure A.6: TOW 2A Maximum Yaw Acceleration versus Time Profile.

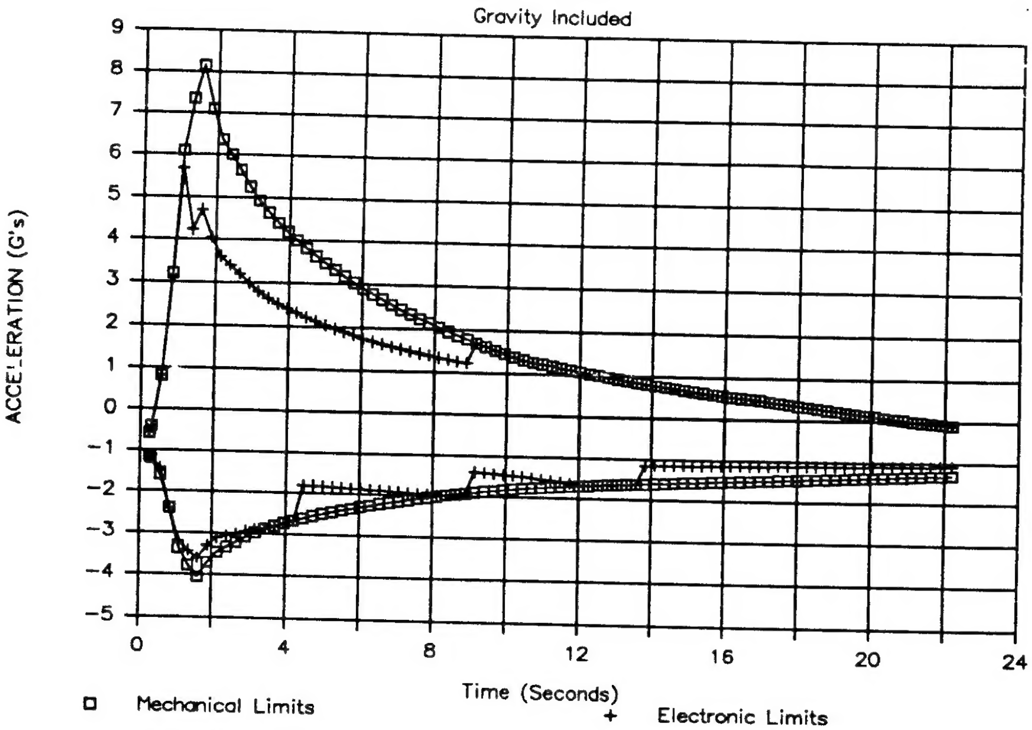

Figure A.7: TOW 2B Maximum Pitch Acceleration versus Time Profile.

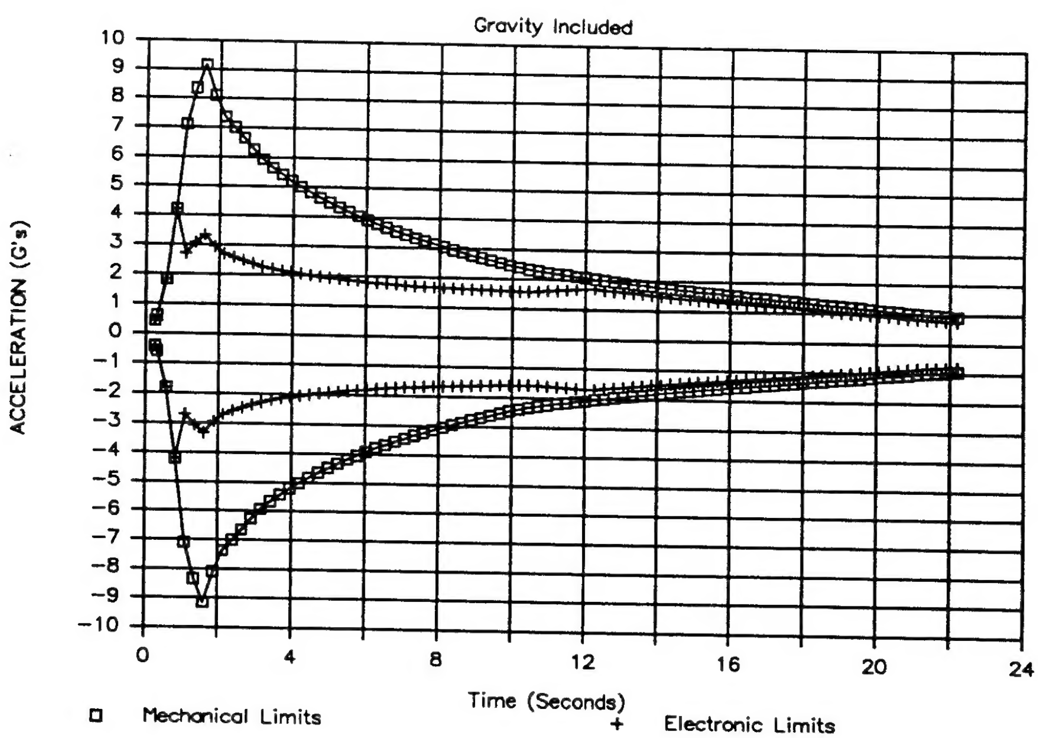

Figure A.8: TOW 2B Maximum Yaw Acceleration versus Time Profile.

Annex B The MICOM TOW simulation

The MICOM TOW simulation program was acquired from the US Army Missile Command. It is currently under development by both MICOM and TNO-PML, and has a development history of more than 15 years. The source code of the program consists of in total some 55000 lines of FORTRAN. Over the years, the results generated by the flight simulation model have been compared to data gathered from flight trials performed at the Redstone Arsenal proving ground. Some general characteristics of the model are given below:

- it uses a 6 Degrees-Of-Freedom (6DOF) flight simulation model for the generation of the missile trajectory;
- it is possible to simulate all TOW missile types from Basic TOW to TOW2B;
- for each TOW missile configuration, a detailed wind-tunnel derived aerodynamic data set is available and there is an option to use linearized derivatives of the wind-tunnel data;
- the implemented launchers are the tripod, the Improved TOW vehicle and the Bradley vehicle;
- the guidance and control system and the sensor systems in the launcher are modelled in detail. Some of the simulation code is a direct FORTAN emulation of the actual software used in the fielded system. This part of the code was modified from the TOW guidance software acquired from Hughes Aircraft Company;
- flight characteristics can be analysed statistically through Monte Carlo simulations, where about 40 random disturbances can be applied. Performance parameters like missile flight stability and the probability of hit can be computed.

In 1992, the MICOM TOW simulation was installed on a Silicon Graphic workstation at the Weapon Effectiveness Research Group at TNO-PML. Since the installation, the simulation model and the documentation [12], [13] have been updated regularly.

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Under assignment from the Royal Netherlands Army Materiel Directorate /Info.Systems Division (DMKL/Afdeling Info. Systemen), the TNO Prins Maurits Laboratory (TNO-PML) conducted a study to investigate the different system boundaries of the TOW weapon system. Both the gunner-related and not-gunner-related system boundaries were considered. An important goal of this study was to investigate the possibility of improving the SST evaluation session so that the SST instructors can conduct quick and correct assessment of the gunner's firing performance. The demanded SST modifications and the relevant output data are described in this report.

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